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RISK EVALUATION OF PIN JIG WORK UNIT IN SHIPBUILDING BY USING FUZZY AHP METHOD

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Professional paper

Summary

Shipbuilding industry includes many different industry branches in itself so various kind of work accidents occur. These work accidents often cause serious injuries and also deaths. It is a crucial thing to prevent or minimize these accidents. In order to reduce work accidents in shipyards, the most hazardous activities are needed to be determined and then, shipyard management must work on it in order to remove these hazard sources. In this study, pin jig work unit, where the curved parts are mounted on adjustable pin jigs, was considered. At first, the work activities and operations of pin jig work station were identified and they were classified as main and sub risk criterions. Then, pair comparison scales were built and these risk criterions were evaluated by experts who have been working for a shipyard located in Turkey. As a result of the evaluations of the experts, the risk weights of the activities carried out at pin jig work unit were defined by using fuzzy AHP method. Therefore, it is aimed for the shipyard management to take some precautions at pinjig work unit on the risky operations before failures happen.

Key words: *Shipyard, risk criterions, risk evaluation, pin jigs, fuzzy AHP*

1. Introduction

Shipbuilding is a heavy industry that the vessel production is performed and it includes many different work branches. The fact that it includes various industry fields and has different sort of work activities increase the accidents occurring in shipyards. The quantity and severity of the accidents have been increasing for years in Turkish shipyards and many serious injuries and also deaths have taken place. It is a very important thing to remove or minimize the failures in many ways.

In literature, there are many works regarding fuzzy AHP and risk evaluation. Zeng et al [1] used a modified Analytic Hierarchy Process (AHP) in order to determine the risks on steel erection in a shopping centre construction. Morate and Vila [2] utilized a fuzzy AHP to determine the risk weights on the rehabilitation project of a building at the University of Cartagena. Chan and Kumar [3] determined the risk weights in selecting global supplier by using Fuzzy Extended Analytic Hierarchy Process (FEAHP). Mustafa and Al-bahar [4] used AHP in the assessment of the riskiness of constructing the Jamuna Multipurpose Bridge in Bangladesh. Wu et al [5] presented some risk factors in selecting appropriate suppliers and determined the weights of these risk factors using AHP. Tsaur et al [6] used an Analytic Hierarchy Process (AHP) method to determine the weighting of some risk evaluation criteria defining tourist evaluation in selecting package tour. Liu and Tsai [7] developed a fuzzy analytic network process (ANP) method to define important hazard types and hazard causes and made an application in telecom engineering company in Taiwan. Grassi et al [8] proposed a risk evaluation method by using fuzzy logic theory and implemented the proposed method on mortadella production process.

In shipbuilding, there are also various studies concerning shipyard risk evaluation. Barlas [9] investigated the fatal occupational accidents in Turkey shipyards and classified them according to fatality reason, age etc. and presented some results based on statistical data. Barlas [10] used AHP in order to find the most suitable precautions for prevention from accidents occurred in Turkish shipyards and made some suggestions to reduce fatality reason. Shinoda et al [11] analyzed occupational accidents in Japanese shipyards and classified the failures to accident types, occurrence date, occurrence site etc., so presented the shipyard accidents in detail. Celebi et al [12] investigated all wastes and pollutants on worker health resulting from shipyard activities and also analyzed accidential injuries in Turkish shipyard.

In this study, the work unit called as pin jig was taken into consideration and a risk evaluation based on fuzzy AHP (Analytic Hierarchy Process) was carried out. For this, firstly, main risk criterions, which may be source of potential risks, were identified and then sub risk criterions were defined for each main risk criterion. After main and sub risk criterions were determined, pair wise comparison scales were built up between main and sub risk criterions. These scales were submitted to the experts in order to take their evaluations and the risk weights of the risk criterions were calculated by using Buckley’s method.

Furthermore, number of three experts, who are naval architecture and marine engineers, evaluated the perfomence criterions. They work at the department of quality control of a shipyard located in Tuzla Region in Istanbul/Turkey.

2. Pin Jig Work Unit

It is almost impossible to perform the mounting and welding activities of curves panel and stiffeners on a flat surface. Therefore, pin jigs are needed to complete the necessary operations of curved parts and sections. At pin jig work unit which is situated in shipyard production system, there are adjustable pins which are used in fixing the curved panel and stiffener in order to facilitate the mounting, welding and grinding operations. Each curved block, which form the vessel structure, is placed on heightened pin jigs and it is not moved until its assembly work is finished once it has been positioned [13]. Figure 1 shows the general arrangement of pin jig work unit in SIMIO simulation environment.

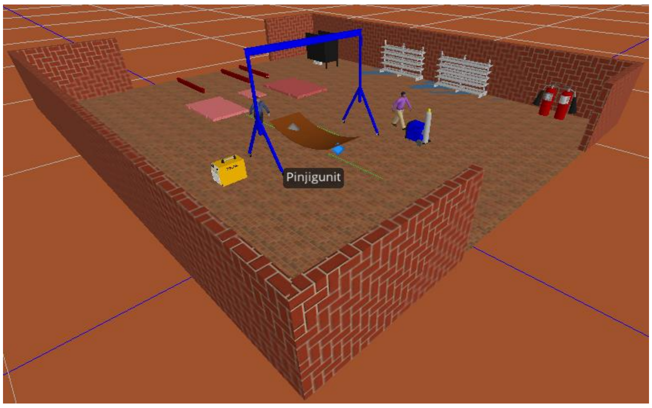

Fig. 1 General arrangement of pinjig work unit

Figure 2 depicts the curved panel on adjustable pins. At the beginning, the first curved plate is positioned on pin jigs and the second plate is fixed near the first one. Then, they are assembled together by welding. If necessary, the other plates are welded together in the same way. Finally, a curved panel of a block is fabricated.

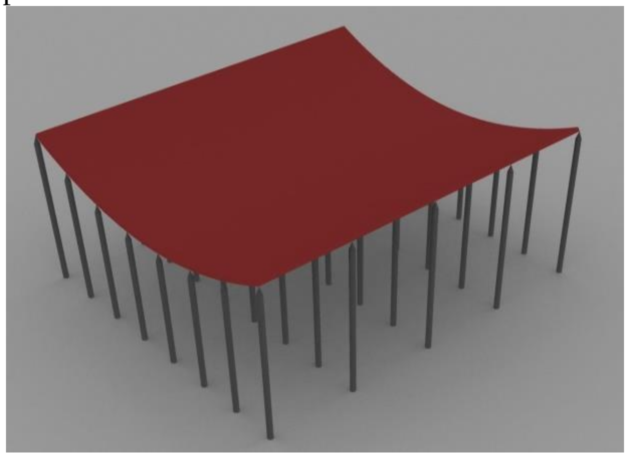

Fig. 2 Curved panel on pin jig

Figure 3 demonstrates the curved panel with stiffeneres. Upon the curved panel, the stiffeners are lined and fixed by fillet weld and the curved panel with stiffeners is manufactured in this way.

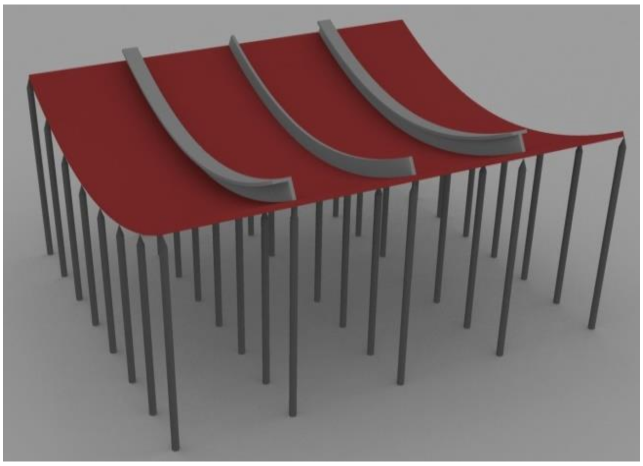

Fig. 3 Curved panel with stiffeners on pin jig

Pin jig work unit is fed by the parts coming from nesting, pre-production, frame bending, and plate bending work units. Curved stiffeners, minor assembly and sub assembly structures are mounted at this work unit and finally they constitute a curved block of the vessel. A general work flow at pin jig is illustrated in Figure 4.

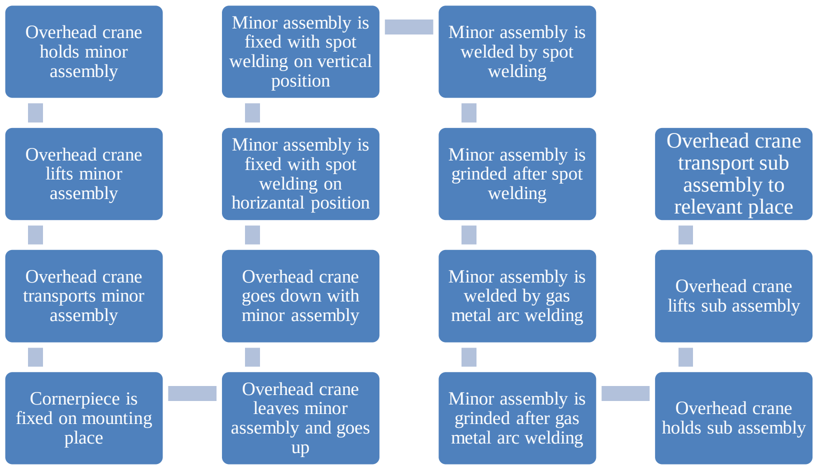

Fig. 4 Work flow of pin jig work unit

3. Materials and Methods

The evaluations of the experts or individuals are able to be easily expressed with fuzzy logic. If a person is needed to make a decision, he could express his evaluations using linguistic statements instead of assigning any crisp score to the evaluations and fuzzy AHP is presented for the purpose of resolving lack of manifesting human perception and thought of AHP developed by Thomas Saaty [14]. In this work, Buckley's technique was utilized.

In the first step of the study, the definition of the performance parameters is carried out and main and sub criterions are determined. In the second step, identification of the linguistic terms including fuzzy numbers are performed. Then, the comparison scales are formed and submitted to the experts in order for them to evaluate and collected finally (Step 3). In the next step (Step 4), the linguistic expressions are transformed into fuzzy numbers. In Step 5, the evaluations of the experts are aggregated and aggregated pair wise matrix is created. Then, the criteria weights are calculated by utilizing Buckley's fuzzy AHP in order to determine the effects of the parameters on decision making (Step 6). In Step 7, the normalization of the fuzzy numbers are carried out in order to find the crisp values and in the last step of the study (Step 8), relative criteria weights are calculated so as to separately determine the effects of each criteria.

3.1 Definition of performance parameters (Step 1)

In this step, the performance parameters or criterions are determined. The performance criterions are divided into two parts which are called "main criterion" and "sub criterion". At first, main criterions are identified. Then, for each main criterion, sub criterions are defined.

3.2 Identification of the linguistic terms (Step 2)

In this step, linguistic scale and fuzzy numbers utilized in this study are identified by benefiting from literature.

3.3 Collecting of expert preferences (Step 3)

Expert opinions or preferences concerning performance criterions are collected by utilizing a questionnaire. Experts evaluate performance criterions by using a pairwise comparison scale. Fuzzy decision matrix is demonstrated as below:

$$\tilde{C}^k = \begin{bmatrix} 1 & \tilde{c}_{12} & \dots & \tilde{c}_{1n} \\ \tilde{c}_{21} & 1 & \dots & \tilde{c}_{2n} \\ \vdots & \vdots & \vdots\vdots\vdots & \vdots \\ \tilde{c}_{m1} & \tilde{c}_{m2} & \dots & 1 \end{bmatrix} \tag{1}$$

$$\tilde{c}_{ij} = \begin{cases} \text{If the criterion at row is more important than at column,} & \begin{cases} \text{Row demon. im.} \\ \text{Row very str. im.} \\ \text{Row str. im.} \\ \text{Row mode. im.} \end{cases} \\ \text{If the criterion at row is same important with at column.,} & \{\text{Row - column eq.} \\ \text{If the criterion at column is more important than at row,} & \begin{cases} \text{Column mode. im.} \\ \text{Column str. im.} \\ \text{Column ver y str im.} \\ \text{Column demon. im.} \end{cases} \end{cases} \tag{2}$$

where $\tilde{C}^k$ is fuzzy decision matrix given by k^{th} expert for importance degrees of criteria.

In Equation 2, there are some abbreviations due to a lack of space on page. Here, “row demon. im.” means row is demonstrated important in comparison with column. Furthermore, “row very str. im.” implies that row has very strong importance according to column while “row str. im.” implies row has strong importance. Moreover, “row mode. im.” means that row has moderate importance while “row-column eq.” is meaning that row and column have equal importance degree. The same definitions are valid for column abbreviations in Equation 2.

3.4 Data transformation into triangular fuzzy numbers (TFN) (Step 4)

Linguistic statements coming from experts must be expressed into triangular fuzzy numbers (TFN) because linguistic statements are not mathematically operable. A TFN is represented by a membership function and $\mu_{\tilde{n}}(x)$, in the range [0, 1] defines the membership degree of the fuzzy number to a fuzzy set [15]. A triangular fuzzy number is shown as below;

$$\mu_{\tilde{n}}(x) = \begin{cases} if \quad n_1 \le x \le n_2, & (x - n_1)/(n_2 - n_1) \\ if \quad n_2 \le x \le n_3, & (n_3 - x)/(n_3 - n_2) \\ if \quad x > n_3 \ or \ x < n_1, & 0 \end{cases} \tag{3}$$

where $\mu_{\tilde{n}}(x)$ is membership function; n_1 is lower boundary; n_3 is upper boundary; n_2 is mean value. Figure 5 depicts a triangular fuzzy number.

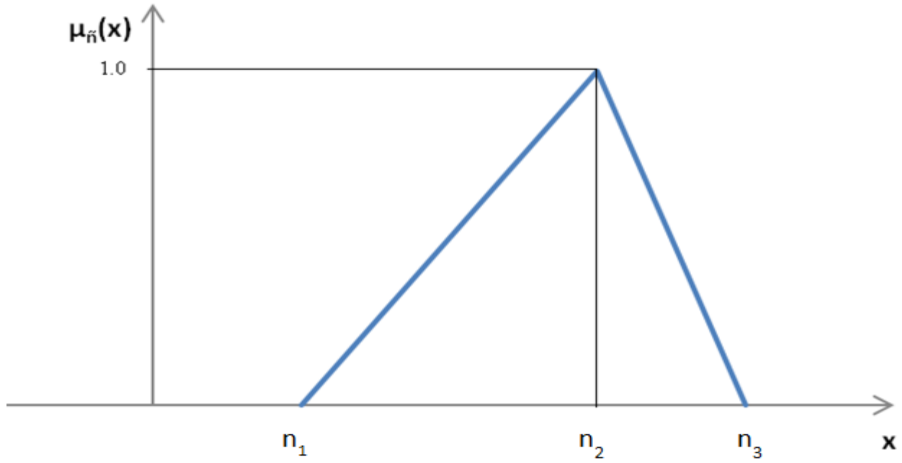

Fig.5 ñ= (n_1, n_2, n_3) triangular fuzzy number

3.5 Collection of the experts' evaluations (Step 5)

At this stage, the evaluations of the experts are aggregated. The weighted average method is utilized in order to aggregate the preferences of the experts. Aggregated pair wise matrix is defined as below:

$$\tilde{C} = \begin{bmatrix} 1 & \tilde{c}_{12} & \cdots & \tilde{c}_{1n} \\ \tilde{c}_{21} & 1 & \cdots & \tilde{c}_{2n} \\ \vdots & \vdots & \vdots\vdots\vdots & \vdots \\ \tilde{c}_{m1} & \tilde{c}_{m2} & \cdots & 1 \end{bmatrix} \quad (4)$$

where $\tilde{C}$ is aggregated pair wise comparison matrix in accordance with importance degrees of criteria.

3.6 Calculation of criteria weights (Step 6)

In this study, Buckley's fuzzy AHP is used to determine the fuzzy weights. After aggregated pair wise matrix ($\tilde{C}$) is achieved, the fuzzy weight matrix is determined by Buckley's Method as below:

$$\tilde{r}_i = (\tilde{c}_{i1} \otimes \tilde{c}_{i2} \otimes \ldots \otimes \tilde{c}_{in})^{1/n} \quad (5)$$

$$\tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 + \tilde{r}_2 + \ldots + \tilde{r}_n)^{-1} \quad (6)$$

where $\tilde{c}_{in}$ is the fuzzy comparison value of criterion i to criterion n, $\tilde{r}_i$ is the geometric mean of fuzzy comparison value of criterion i to each criterion.

3.7 Defuzzification and normalization process for fuzzy weights (Step 7)

In order to transform the fuzzy weights into crisp values, median method is implemented:

$$w_i = \frac{n_1 + n_2 + n_3}{3} \quad (7)$$

where n_1 is lower boundary; n_3 is upper boundary; n_2 is mean value of fuzzy weight. Crisp values are normalized to have more comprehensible results by using Eq. 8 [16].

$$(w_N)_i^c = \frac{w_i^c}{\sum_{i=1}^{n} w_i^c} \quad (8)$$

where $(w_N)_i^c$ is normalized weight of i^{th} main criterion, n is number of main criteria; for sub criteria the Eq. 9 is used:

$$(w_N)_i^{sc} = \frac{w_i^{sc}}{\sum_{i=1}^{n} w_i^{sc}} \quad (9)$$

where $(w_N)_i^{sc}$ is normalized weight of i^{th} sub criterion, n is number of sub criteria.

3.8 Calculation of relative criteria weights (Step 8)

In order to evaluate sub criteria between themselves, relative fuzzy weights and relative crisp weights are calculated by utilizing Eq. 10 and Eq. 11,

$$(\tilde{w}_R)_i^{sc} = (\tilde{w})^c \otimes (\tilde{w})_i^{sc} \quad (10)$$

where $(\tilde{w}_R)_i^{sc}$ is relative fuzzy weight of i^{th} sub criterion, $(\tilde{w})^c$ is fuzzy weight of main criterion which includes that sub criterion, $(\tilde{w})_i^{sc}$ is fuzzy weight of i^{th} sub criterion.

$$(w_R)_i^{sc} = (w_N)^c \times (w_N)_i^{sc} \quad (11)$$

where $(w_R)_i^{sc}$ is relative crisp weight of i^{th} sub criterion, $(w_N)^c$ is normalized crisp weight of main criterion which includes that sub criterion, $(w_N)_i^{sc}$ is normalized crisp weight of i^{th} sub criterion.

4. Results and Discussions

In this study, three experts who work in Turkish shipyards evaluated the performance criterions and the assessments of experts were collected and considered in determining the weights of the criterions.

4.1 Determination of criterions (Step 1)

In this section, the risk criterions in pin jig workshop were determined. Four main criterions specified as “crane movements, welding, grinding, and mounting” were defined. Under these main risk criterions, sub risk criterions were defined. Figure 6 and Table 1 show the main and sub risk criterions.

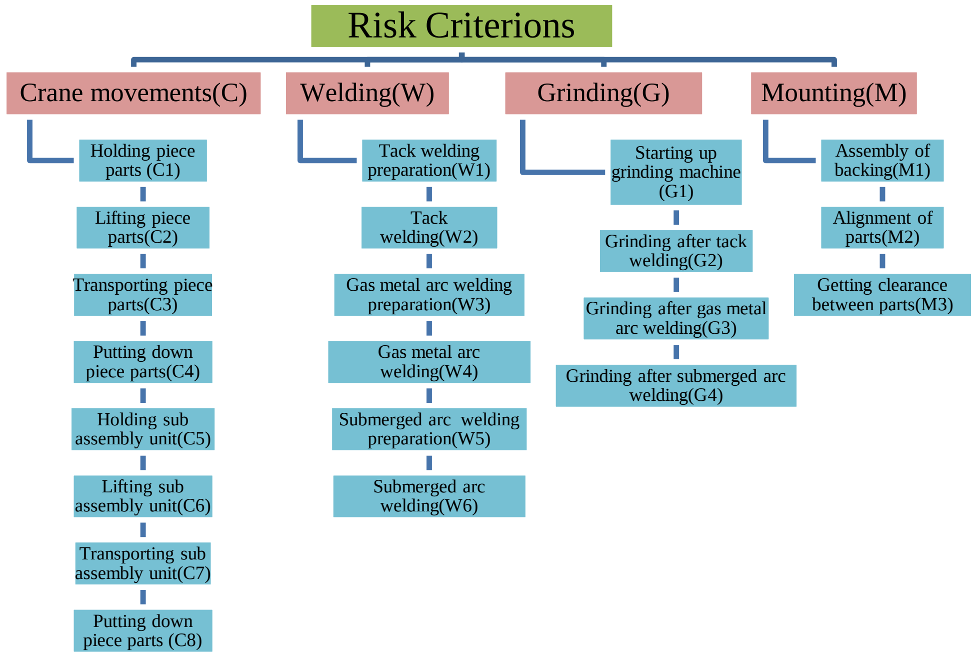

Fig. 6 Main and sub risk criterions used in the study

Table 1 Definitions of sub risk criterions

Risk criterions	Definition
Holding piece parts (C1)	How much risk is there when the crane holds the surface of the piece parts in order to lift it up?
Lifting piece parts (C2)	How much risk is there when the crane lifts the piece parts?
Transporting piece parts (C3)	How much risk is there when the crane transports the piece parts to the places where they are needed?
Putting down piece parts (C4)	How much risk is there when the crane puts the piece parts on the ground?
Holding sub assembly unit (C5)	How much risk is there when the crane holds the surface of sub assembly unit in order to lift it up?
Lifting sub assembly unit (C6)	How much risk is there when the crane lifts sub assembly unit?
Transporting sub assembly unit (C7)	How much risk is there when the crane transports sub assembly unit to the places where they are needed?
Putting down sub assembly unit (C8)	How much risk is there when the crane puts sub assembly unit on the ground?
Tack welding preparation (W1)	How much risk is there when the worker is preparing the tack welding machine and torch before doing tack welding operation?
Tack welding (W2)	How much risk is there when the worker connects the parts with tack welding?
Gas metal arc welding preparation (W3)	How much risk is there when the operator is preparing the gas metal arc welding machine and torch before performing gas metal arc welding activity?
Gas metal arc welding (W4)	How much risk is there during assembling the parts with gas metal arc welding?
Submerged arc welding preparation (W5)	How much risk is there when the worker is preparing the submerged arc welding machine and torch before carrying out submerged arc welding operation?
Submerged arc welding (W6)	How much risk is there while assembling the parts with submerged arc welding?
Starting up grinding machine (G1)	How much risk is there while operator is activating the grinding machine before starting grinding operation?
Grinding after tack welding (G2)	How much risk is there while performing grinding activity after tack welding operation?
Grinding after gas metal arc welding (G3)	How much risk is there while carrying out grinding activity after gas metal arc welding operation?
Grinding after submerged arc welding (G4)	How much risk is there while performing grinding activity after submerged arc welding operation?
Assembly of backing (M1)	How much risk is there during assembling the ceramic backing to the connection edges of the plates?
Alignment of parts (M2)	How much risk is there while the parts are aligned on the marking points?
Getting clearance between parts (M3)	How much risk is there while the gaps between the parts are removing?

4.2 Identification of the linguistic statements (Step 2)

Linguistic statements and their fuzzy number definitions performed in this study are demonstrated in Table 2 [17].

Table 2 Linguistic statements and their fuzzy number definitions

Linguistic statements	Fuzzy number definitions
Equal risky	(1,1,1)
Moderate risky	(1,3,5)
Strong risky	(3,5,7)
Very strong risky	(5,7,9)
Demonstrated risky	(7,9,11)

4.3 Collection of expert evaluations (Step 3)

In this step, experts rated the risk parameters according to their experience and the evaluations of them were collected. Here, only Expert 1 evaluation of main risk criterions was illustrated in Table 3.

Table 3 Expert 1 evaluation for main risk criterions

	Crane movements (C)	Welding (W)	Grinding (G)	Mounting (M)
C	-	Column very str. risky	Column demon. risky	Column demon. risky
W	Row very str. risky	-	Column very str. risky	Column mode. risky
G	Row demon. risky	Row very str. risky	-	Row-column eq. risky
M	Row demon. risky	Row mode. risky	Row-column eq. risky	-

4.4 Conversion of linguistic statements into triangular fuzzy numbers (TFN) (Step 4)

In this step, the expert evaluations, which include linguistic statements, were converted to triangular fuzzy numbers. In the same way, for only Expert 1's evaluation, the fuzzy number transformation was demonstrated here. Table 4 shows the evaluation of Expert 1 with fuzzy numbers.

Table 4 Expert 1 evaluation for main risk criterions with fuzzy numbers

	Crane movements (C)	Welding (W)	Grinding (G)	Mounting (M)
C	(1.000,1.000,1.000)	(0.111,0.143,0.200)	(0.091,0.111,0.143)	(0.091,0.111,0.143)
W	(5.000,7.000,9.000)	(1.000,1.000,1.000)	(0.111,0.143,0.200)	(0.200,0.333,1.000)
G	(7.000,9.000,11.000)	(5.000,7.000,9.000)	(1.000,1.000,1.000)	(1.000,1.000,1.000)
M	(7.000,9.000,11.000)	(1.000,3.000,5.000)	(1.000,1.000,1.000)	(1.000,1.000,1.000)

4.5 Aggregation of the evaluations of the experts (Step 5)

As mentioned above, there are three experts who rate the risk criterions. In this section, the evaluations of the experts were aggregated. The aggregated fuzzy decision matrix was demonstrated in Table 5-10.

Table 5 Aggregated values for main risk criterions

	Crane movements (C)	Welding (W)	Grinding (G)	Mounting (M)
C	(1.000,1.000,1.000)	(3.370,4.714,6.066)	(2.697,4.037,5.381)	(4.030,5.370,6.714)
W	(1.745,2.437,3.158)	(1.000,1.000,1.000)	(1.104,1.825,2.733)	(0.733,2.111,3.667)
G	(1.745,2.437,3.158)	(2.047,3.400,4.777)	(1.000,1.000,1.000)	(1.000,1.667,2.333)
M	(2.400,3.085,3.781)	(0.467,1.222,2.333)	(0.733,0.778,1.000)	(1.000,1.000,1.000)

Table 6 Aggregated values for risk criterions based on crane movements

	Holding piece parts (C1)	Lifting piece parts (C2)	Transporting piece parts (C3)	Putting down piece parts (C4)
C1	(1.000,1.000,1.000)	(0.411,0.437,0.492)	(0.108,0.141,0.206)	(0.126,0.170,0.270)
C2	(3.667,5.000,6.333)	(1.000,1.000,1.000)	(0.145,0.215,0.492)	(0.714,1.400,2.111)
C3	(5.667,7.667,9.667)	(3.667,5.667,7.667)	(1.000,1.000,1.000)	(2.333,3.000,3.667)
C4	(4.333,6.333,8.333)	(1.400,2.111,3.000)	(0.704,0.714,0.733)	(1.000,1.000,1.000)
C5	(2.067,2.777,3.667)	(0.430,1.148,2.048)	(0.126,0.170,0.270)	(0.200,0.333,1.000)
C6	(1.400,2.777,4.333)	(1.381,2.067,2.778)	(0.430,0.481,0.714)	(2.333,3.667,5.000)
C7	(4.333,6.333,8.333)	(1.667,3.000,4.333)	(2.067,2.778,3.667)	(2.067,2.778,3.667)
C8	(3.000,5.000,7.000)	(2.704,4.048,5.400)	(0.704,0.714,0.733)	(2.333,3.000,3.667)

Table 7 Aggregated values for risk criterions based on crane movements (continue)

	Holding sub assembly unit (C5)	Lifting sub assembly unit (C6)	Transporting sub assembly unit (C7)	Putting down sub assembly unit (C8)
C1	(0.704,1.381,2.067)	(0.448,1.178,2.111)	(0.134,0.196,0.448)	(0.143,0.200,0.333)
C2	(2.733,4.111,5.667)	(1.381,2.067,2.778)	(0.448,0.511,0.778)	(1.764,2.481,3.381)
C3	(4.333,6.333,8.333)	(3.000,4.333,5.667)	(0.704,1.381,2.067)	(2.333,3.000,3.667)
C4	(1.000,3.000,5.000)	(0.437,0.492,0.733)	(0.704,1.381,2.067)	(0.704,0.714,0.733)
C5	(1.000,1.000,1.000)	(0.126,0.170,0.270)	(0.448,0.511,0.778)	(0.162,0.244,0.555)
C6	(4.333,6.333,8.333)	(1.000,1.000,1.000)	(2.067,3.444,5.000)	(2.067,3.444,5.000)
C7	(1.667,3.000,4.333)	(0.437,1.159,2.067)	(1.000,1.000,1.000)	(2.733,3.444,4.333)
C8	(2.333,4.333,6.333)	(0.437,1.159,2.067)	(0.697,1.370,2.048)	(1.000,1.000,1.000)

Table 8 Aggregated values for risk criterions based on welding operation

	Tack welding preparation (W1)	Tack welding (W2)	Gas metal arc welding preparation (W3)	Gas metal arc welding (W4)	Submerged arc welding preparation (W5)	Submerged arc welding (W6)
W1	(1.000,1.000,1.000)	(1.097,1.815,2.714)	(0.437,1.159,2.067)	(1.078,1.770,2.492)	(1.114,1.844,2.778)	(1.085,1.781,2.511)
W2	(2.714,4.067,5.444)	(1.000,1.000,1.000)	(2.067,3.444,5.000)	(0.448,1.178,2.111)	(1.667,3.667,5.667)	(0.467,1.222,2.333)
W3	(2.067,3.444,5.000)	(0.437,1.159,2.067)	(1.000,1.000,1.000)	(3.381,4.733,6.111)	(1.000,1.000,1.000)	(0.437,1.159,2.067)
W4	(3.381,4.733,6.111)	(1.400,2.778,4.333)	(1.078,1.770,2.492)	(1.000,1.000,1.000)	(3.400,4.778,6.333)	(2.333,4.333,6.333)
W5	(1.381,2.733,4.111)	(0.181,0.289,0.778)	(1.000,1.000,1.000)	(0.411,1.104,1.825)	(1.000,1.000,1.000)	(3.400,4.778,6.333)
W6	(2.714,4.067,5.444)	(0.733,2.111,3.667)	(2.067,3.444,5.000)	(0.162,0.244,0.555)	(0.411,1.104,1.825)	(1.000,1.000,1.000)

Table 9 Aggregated values for risk criterions based on grinding operation

	Starting up grinding machine (G1)	Grinding after tack welding (G2)	Grinding after gas metal arc welding (G3)	Grinding after submerged arc welding (G4)
G1	(1.000,1.000,1.000)	(2.437,3.159,4.067)	(2.437,3.159,4.067)	(2.437,3.159,4.067)
G2	(2.030,3.370,4.714)	(1.000,1.000,1.000)	(1.800,2.555,3.667)	(2.733,4.111,5.667)
G3	(2.030,3.370,4.714)	(0.704,2.048,3.400)	(1.000,1.000,1.000)	(1.667,3.667,5.667)
G4	(2.030,3.370,4.714)	(0.418,1.114,1.844)	(0.181,0.289,0.778)	(1.000,1.000,1.000)

Table 10 Aggregated values for risk criterions based on mounting operation

	Assembly of backing (M1)	Alignment of parts (M2)	Getting clearance between parts (M3)
M1	(1.000,1.000,1.000)	(0.151,0.225,0.511)	(0.151,0.225,0.511)
M2	(3.000,5.000,7.000)	(1.000,1.000,1.000)	(0.429,1.133,1.889)
M3	(3.000,5.000,7.000)	(2.067,3.444,5.000)	(1.000,1.000,1.000)

4.6 Determination of criterion weights (Step 6), defuzzification and normalization procedure for fuzzy weights (Step 7) and calculation of relative criteria weights (Step 8)

In this stage, three steps of the methodology were completed. The significance degrees of risk parameters were calculated according to Buckley's Fuzzy AHP and the results are shown in Table 11.

Table 11 The significance degrees of risk criterions

Main and sub risk criterions	**Overall fuzzy weights**	**Relative fuzzy weights**	**Crisp**	**Relative crisp**
Crane movements (C)	**(0.234, 0.383, 0.642)**		**0.378**	
Holding piece parts (C1)	(0.015, 0.029, 0.063)	(0.003, 0.011, 0.041)	0.031	0.012
Lifting piece parts (C2)	(0.054, 0.102, 0.211)	(0.013, 0.039, 0.135)	0.106	0.040
Transporting piece parts (C3)	(0.128, 0.239, 0.439)	(0.030, 0.092, 0.282)	0.233	0.088
Putting down piece parts (C4)	(0.053, 0.100, 0.186)	(0.012, 0.038, 0.120)	0.098	0.037
Holding sub assembly unit (C5)	(0.019, 0.036, 0.087)	(0.004, 0.014, 0.056)	0.041	0.015
Lifting sub assembly unit(C6)	(0.084, 0.165, 0.326)	(0.020, 0.063, 0.209)	0.166	0.063
Transporting sub assembly unit (C7)	(0.090, 0.183, 0.358)	(0.021, 0.070, 0.229)	0.182	0.069
Putting down sub assembly unit (C8)	(0.071, 0.147, 0.281)	(0.017, 0.056, 0.180)	0.144	0.054
Welding (W)	**(0.103, 0.211, 0.396)**		**0.214**	
Tack welding preparation (W1)	(0.061, 0.142, 0.326)	(0.006, 0.030, 0.129)	0.142	0.030
Tack welding (W2)	(0.074, 0.191, 0.458)	(0.008, 0.040, 0.181)	0.194	0.041
Gas metal arc welding preparation (W3)	(0.069, 0.156, 0.342)	(0.007, 0.033, 0.135)	0.152	0.032
Gas metal arc welding (W4)	(0.123, 0.261, 0.564)	(0.013, 0.055, 0.223)	0.254	0.054
Submerged arc welding preparation (W5)	(0.056, 0.118, 0.277)	(0.006, 0.025, 0.110)	0.121	0.026
Submerged arc welding (W6)	(0.053, 0.132, 0.328)	(0.006, 0.028, 0.130)	0.137	0.029
Grinding (G)	**(0.142, 0.248, 0.432)**		**0.247**	
Starting up grinding machine (G1)	(0.182, 0.294, 0.512)	(0.026, 0.073, 0.221)	0.287	0.071
Grinding after tack welding (G2)	(0.166, 0.302, 0.562)	(0.024, 0.075, 0.243)	0.300	0.074
Grinding after gas metal arc welding (G3)	(0.116, 0.278, 0.552)	(0.016, 0.069, 0.238)	0.275	0.068
Grinding after submerged arc welding (G4)	(0.058, 0.126, 0.288)	(0.008, 0.031, 0.125)	0.138	0.034
Mounting (M)	**(0.090, 0.158, 0.287)**		**0.161**	
Assembly of backing (M1)	(0.045, 0.078, 0.199)	(0.004, 0.012, 0.057)	0.093	0.015
Alignment of parts (M2)	(0.173, 0.376, 0.737)	(0.016, 0.059, 0.212)	0.371	0.060
Getting clearance between parts (M3)	(0.293, 0.545, 1.019)	(0.026, 0.086, 0.293)	0.536	0.086

The most risky criterion was found to be crane movement in comparison with the other main risk criterions such as welding, grinding and mounting. Besides, the grinding activity was the second one as risk level at pin jig work unit. Figure 7 depicts the risk weights of main risk criterions.

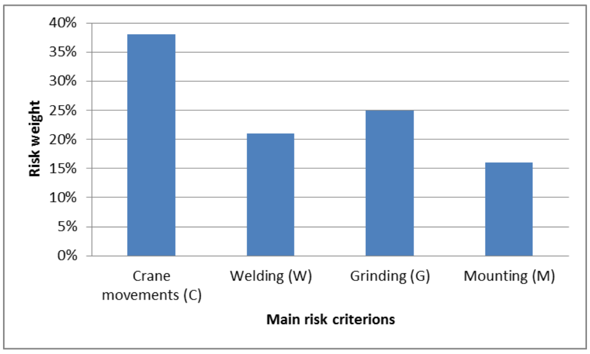

Fig. 7 Risk weights of main risk criterions

Furthermore, the most risky activity is to transport piece parts (C3) in crane movements. Transporting sub assembly unit (C7) is the second most risky activity. The least risky activity is to hold piece parts (C1). Figure 8 demonstrates the risk weights of sub risk criterions.

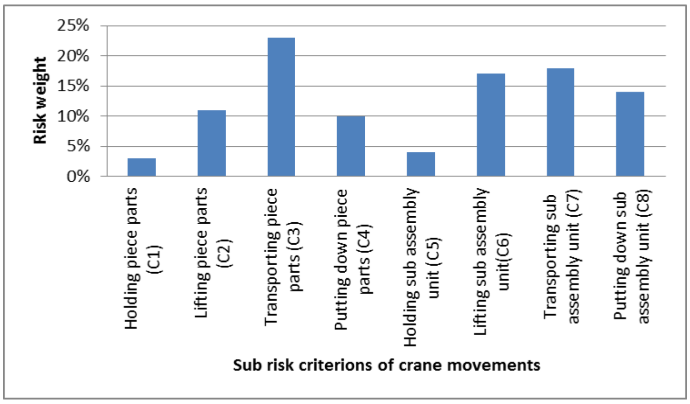

Fig. 8 Risk weights of sub risk criterions of crane movement

Figure 9 demonstrates the risk weights of sub risk criterions of welding operation. It was seen that the most risky activity was based on Gas Metal Arc Welding (W4). Tack welding is the second one.

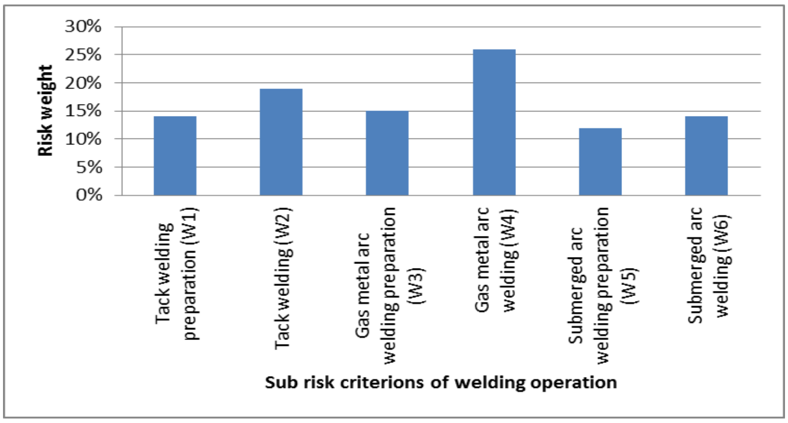

Fig. 9 Risk weights of sub risk criterions of welding operation

Figure 10 shows the risk weights of sub risk criterions of grinding operation. It can be seen that the grinding activity after tack welding is the most risky activity.

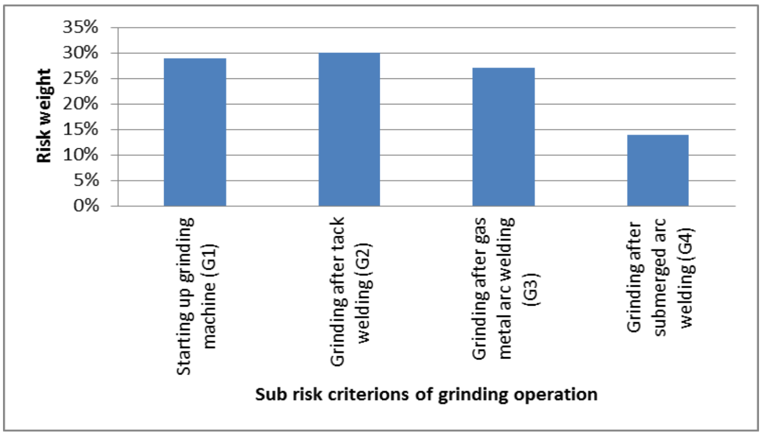

Fig. 10 Risk weights of sub risk criterions of grinding operation

In Figure 11, risk weights based on mounting operation are shown. According to this, the activity of getting clearance between parts is the most risky mounting activity. The second most risky one is the activity of alignment of parts.

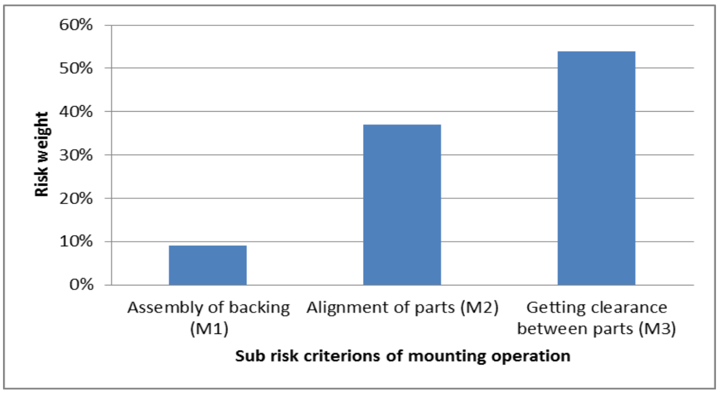

Fig. 11 Risk weights of sub risk criterions of mounting operation

In Figure 12, the whole sub risk criterions (or sub activities in other words) and their risk weights were demonstrated. Getting clearance between parts (M3) and transporting piece parts (C3) have a risk weight of approximately 9%. On the other hand, transporting sub assembly unit (C7), starting-up grinding machine (G1), grinding after tack welding (G2), and grinding after gas metal arc welding (G3) have a risk weight of around 7%. Holding piece parts (C1), holding sub assembly unit (C5), and assembly of backing (M1) have least weights, 2% and 1% respectively.

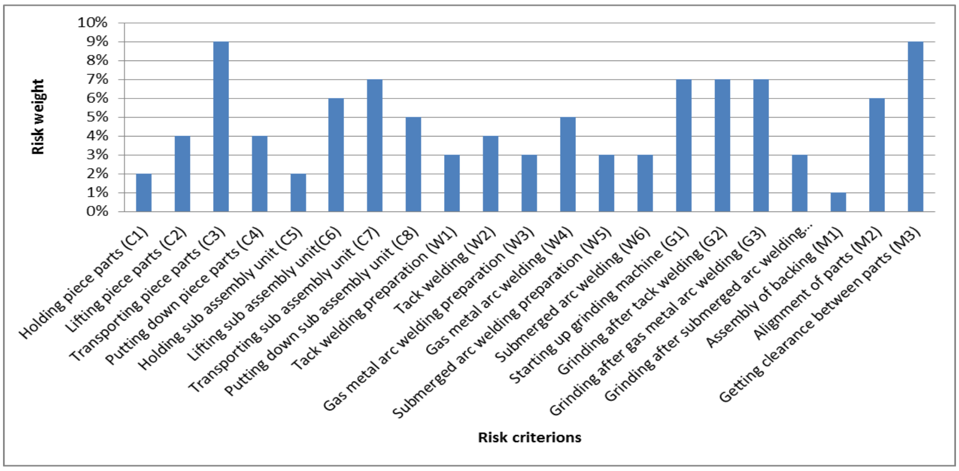

Fig. 12 Risk weights of sub risk criterions

5. Conclusion

According to the evaluations of experts, the most risky activities in pin jig work unit are those transporting piece parts (C3) and getting clearance between parts (M3) because they have the highest risk weights. The other risky activities are transporting sub assembly unit (C7), starting-up grinding machine (G1), grinding after tack welding (G2), and grinding after gas metal arc welding (G3), lifting sub assembly unit (C6), alignment of parts (M2), respectively.

Therefore, shipyard management must investigate the processes of transportation of the parts at pin jig work unit and remove the hazardous risk sources or attempt to minimize them. Furthermore, fairing activity (or getting clearance between parts) was found to be the other most risky activity at pin jig work unit. In the same way, the shipyard management must examine the fairing activity in detailed and try to reduce the hazardous risk sources.

This kind of risk assessment presented in this study should perform for the other work units at shipyards. If this is done, the most hazardous activities for each work unit could be determined and the work accidents taking place at each work unit can be reduced. In this way, the rates of work loss and injuries can be minimized.

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